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Report 69-3

ACOUSTIC STABILITY AT LONG RANGES UNDER SHORE-FAST ICE (U)

by

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August 1969

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62 DREP
02a 403246
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Classification cancelled / changed to Unclassified 11b
By authority of DREA Document Review Panel
Date 14 Aug 96
Signature B Trenholm per BA
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46 August 1969

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ABSTRACT

In April 1969 an experiment was performed to investigate the stability of sound transmission under shore-fast sea ice in M'Clure Strait. CW pulses were used, with a carrier frequency of 2.1 kHz. The signals were received by hydrophones at distances of 10, 20 and 30 miles from the sound source and were telemetered to a recording site on Melville Island. The direct sound transmission paths were very stable, with a maximum change in the sound transmission time of one part per million per minute. These small changes appeared to be due solely to the doppler effect of tidal currents.

The high stability of surface reverberation returns, measured in 1968 at 900 Hz, was confirmed at 2.1 kHz under much smoother ice cover.

Introduction

Earlier measurements (Ref 1) of the stability of sound-paths under shore-fast ice showed that a very stable acoustic environment existed, at least for the short range of two miles. These results raised the possibility of using cancellation techniques to eliminate the effects of surface reverberation and of the development of a sonar equivalent to a Moving Target Indicator Radar. The obvious question was: "Do the stable acoustic conditions hold over longer ranges, such as twenty miles."

DREP personnel returned to the same area of M'Clure Strait (see Figure 1) and set up equipment to perform a direct sound transmission experiment having the geometry shown in Figure 2. The underwater sound projector, shown in Figure 3, was lowered to the bottom by its electrical cable in 1,300 feet of water and was driven by a pulse generator and amplifier in a camp established on the sea ice immediately above. The sound waves generated by the projector were received at four separate remote sites by hydrophones placed just below the ice sheet at nominal ranges of ten, twenty and thirty miles from the camp. Each remote station included a VHF telemetry transmitter, and voltages representing the sound waves could be telemetered over a line-of-sight radio path to a "cliff camp" on Melville Island for further processing. Figure 4 shows a photograph of the "cliff camp" and its telemetry antennas.

The direct sound paths were very stable, in terms of phase and amplitude changes, at all four remote sites. The observed slow changes in phase and amplitude appeared to be due to a doppler shift caused by changing tidal currents. The magnitude of these changes was proportional to the range to the remote sites and was therefore most obvious at a distance of thirty miles. As a result, most of the data was recorded using the sounds received by the remote station at a range of thirty miles.

Direct Transmissions

The sound projector transmitted tone bursts or CW pulses with a carrier frequency of 2150 Hz*. The time of transmission was telemetered to the "cliff camp" and was used to trigger a preset counter. The preset counter then triggered an oscilloscope an exactly known time interval after the reception of the time of transmission. This delay in triggering allowed the oscilloscope to display a specific portion of the sound received at a remote hydrophone from each successive pulse

* See Appendix A for details of the electronics.

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transmission, and permitted the use of a polaroid oscilloscope camera to keep track of the variations in the phase of the received signal. Figure 5 shows samples of the types of phase shifts measured. The pulse repetition rate was one pulse every forty-five seconds, and each photograph shows eleven traces and a total phase shift spanning a period of seven and one half minutes. Figure 5 shows clearly that the phase shifts occurred in a slow, regular pattern and that the phase shifts could be positive, zero or negative. The transition in the trend of the phase shift changes occurred smoothly over a period of hours, and the phase shifts were attributed to the effect of tidal current changes.

From photographs of the kind shown in Figure 5 it is possible to express the change in the arrival times of sounds at the remote sites in microseconds per minute of elapsed time. This data is shown in Figure 6, plotted against the time of day. Figure 6 also shows the component of the tidal current in the direction of the transmission of sound to the remote sites. There are difficulties in the measurement of small tidal currents, especially in an area where a magnetic compass cannot be used. As a result there is some scattering of the points which were used to define the curve of tidal current vs time of day. Appendix B discusses our apparatus and its accuracy limitations. Our hypothesis is that the observed changes in the propagation time are due to the doppler effect caused by changes in the tidal current flow. This implies that the propagation time would be proportional to the amplitude of the tide current component in the direction of the sound path to the remote hydrophones, and that the rate of change of the propagation time (the quantity shown in the bottom curve of Figure 6) would be proportional to the rate of change of the tide current (the differential of the top curve in Figure 6). This relationship is emphasized by the three arrows in Figure 6. When the amplitude of the tidal current is at a maximum and is changing slowly, the rate of change of the sound propagation time is virtually zero. This condition corresponds to the zero phase shifts shown in the middle photograph in Figure 5 and occurred at times depicted in Figure 6 by the arrows labelled "1" and "3". On the other hand, when the tidal current was changing rapidly the rate of change of the sound propagation time was at a maximum. This condition occurred at the time of day shown in Figure 6 by the arrow labelled "2".

The qualitative agreement of the measurements with our hypothesis was remarkably good considering that our current measurements were crude and that these were measured only at one end of the sound path. Figure 6 shows plots of the rate of change of sound propagation time measured at both the twenty mile hydrophone and the thirty mile hydrophone. If the tidal current had been uniform over the whole range to thirty miles, these curves would differ only in amplitude, with the amplitudes having

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the ratio of two to three. The discrepancies from this simple picture indicate the existence of a non-uniform tidal current pattern in M'Clure Strait. An indication of the possible complexity of the tidal current flow is given by the progressive vector diagram of Figure 7.

The quantitative agreement of the measurements with our hypothesis is poor. If the time shown in Figure 6 by the arrow marked "2" is considered, the measured rate of change of tide current in the direction of the sound path was .011 meters per minute per minute. Equivalent values at this same time of day of the rate of change of tide current can be calculated from the rate of change of sound propagation time under the assumption that the changes are caused entirely by the Doppler effect from the tidal current. Phase changes at the twenty mile site indicated a rate of change of tidal current of .027 meters per minute per minute and at the thirty mile site indicated a rate of change of tidal current of .044 meters per minute per minute. As mentioned above, the different values of tidal current rate of change computed from sound wave phase-angle changes at the twenty and thirty mile sites is attributed to non uniform tidal currents in the direction of sound propagation. The calculated values of 0.027 and .044 are more than the measured tidal current rate of change of .011 meters per minute per minute which indicates that our current measurements were made within the boundary layer of low velocity water immediately below the ice sheet. Our current meter produced a weighted average current velocity for the thirteen foot layer of water immediately below the ice sheet (see Appendix B). Measurements of current over the sea bottom** indicate that our measurements were confined almost entirely within the boundary layer under the ice, and this would result in lower observed velocities than actually existed in the main body of the water.

These direct sound path measurements indicated that the acoustic environment beneath shore fast ice is very stable. For this experiment, the maximum changes in the sound propagation time were of the order of one part in a million per minute. The changes in the propagation time appeared to be solely due to the doppler effect caused by tidal current changes.

Reverberation

The 1969 experiment concentrated on the measurement of the stability of direct transmissions of underwater sound. However, some reverberation recordings were made at the camp on the ice in order to compare these with similar reverberation recordings made in 1968 at a lower frequency and under a much rougher ice cover.

** Reference 2, page 579.

Figure 8 shows the first ten seconds of reverberation received by the transducer mounted on the bottom in 1,300 feet of water. The transmitted signal consisted of a tone burst at a frequency of 2,150 Hz, and the ice surface was entirely of annual ice with only slight pressure ridging. Figure 8 shows selected time-segments of the reverberation signal expanded to show the individual cycles of the reverberation. Each expanded signal is actually the superposition of five separate reverberation returns on the same time-base and covering an elapsed time of three minutes. As with the direct transmission, the oscilloscope was triggered a known time after the transmission of the pulse, but in this case the five returns were directly superimposed without any vertical shift between traces. As in the experiment of 1968 (Ref 1) the reverberations remained essentially constant in both amplitude and phase. There were, however, slight dissimilarities in reverberation signals. These dissimilarities were definitely above noise, and were more evident in these recordings primarily as a result of a better signal-to-noise ratio in the equipment than in that used in 1968, but also because of the higher carrier frequency and the lower pulse repetition rate compared to the similar display published in Figure 1 of Reference 1.

Figure 9 shows a sample of the benefits gained by a simple subtraction of one reverberation return from another. A short portion, eight seconds after the transmitted sound, was arbitrarily selected from two reverberation returns received after two pulse transmissions separated by an interval of seven minutes. The cancellation is more effective at shorter ranges and for reverberations received as a result of a shorter time separation between transmitted pulses.

A moving target indicator type of sonar based on subtraction techniques still appears to be a very attractive concept, and our analysis of the reverberation returns is continuing.

Conclusions

The acoustic environment under shore-fast ice is very stable, and this stability extends over sound paths to ranges of at least thirty miles. Those fluctuations in the phase angle of the acoustic waves which do occur are non-random and are caused by the doppler shift associated with tidal currents. This conclusion implies that one of the main parameters necessary to evaluate the acoustic environment in arctic waters covered by shore-fast ice is a knowledge of tidal currents.

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The sequential cancellation of surface reverberations as a useful technique of signal processing was reconfirmed at a different frequency and for a different type of ice cover. A "moving target indicator" type of sonar appears to hold promise for a barrier type of surveillance system.

References

1. "High Stability in Reverberation Under Sea Ice (U)". DREP Report 68-2. J.H. Ganton, A.R. Milne and T. Hughes. June 1968. CONFIDENTIAL.

2. "The Oceans". H.U. Sverdrup, M.W. Johnson and R.H. Fleming, Prentice Hall, 1942.

APPENDIX A

THE INSTRUMENTATION

Figure 10 shows a block diagram of the instrumentation at the "Ice Camp". The carrier frequency was generated by a "General Radio" frequency synthesizer which was phase locked to a crystal oscillator with a nominal stability of ± 2 parts in 10^{+10} per ^{o}C. Micrologic counters in the pulse generator controlled the duration of the tone burst and the pulse repetition rate. The power amplifier drove the cable to the transducer with square waves of voltage at the carrier frequency. However, the matching inductor and the transducer capacitance resonated at 2150 Hz, so that the current waveform in the transducer was reasonably sinusoidal. The acoustical signal in the water was therefore a sequence of coherent tone-bursts with all transmitted tone-bursts identical.

The transducer was a free-flooding ring, type DREA 34C12, designed and built by the Defence Research Establishment Atlantic. This transducer worked very well and was not troubled by the Arctic environment.

The carrier frequency and the tone-burst envelope were telemetered to the "Cliff Camp" by a 230 MHz FM radio link. The VHF telemetry links to the Cliff Camp were very reliable and had uniform and excellent signal-to-noise ratios. In contrast, our HF voice communications were very marginal, even over a fourteen miles line of sight distance, as a result of a radio "blackout" condition.

For reverberation measurements, the transducer on the bottom was used both for transmitting and receiving underwater sounds. The received acoustic signals were amplified, filtered and then recorded as oscilloscope photographs, and on FM magnetic tape. A preset counter was used to trigger the oscilloscope a constant number of cycles of the carrier frequency after the generation of each tone-burst.

Figure 11 shows a block diagram of a "remote hydrophone station". The telemetry transmitters and their FM modulators were exhumed from type 508 sonobuoys, each being mounted adjacent to a six element yagi antenna on a twenty-five foot mast. There was little prior knowledge of the acoustic levels expected or of the length of time required to perform the experiment, consequently HF radio command-links were incorporated in the design of the remote stations to switch the gains of the audio amplifiers and to switch off their transmitters when the remote

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stations were not in use. The storage batteries were pocket-plate nickel-cadmium units with a lifetime of 10 days under continuous discharge conditions at a temperature of -20°F. In the field, the HF command links degenerated in the same way as our HF voice communications, so that once the acoustic signal strengths had been established, the experiment was conducted with the remote stations converted to continuous operation at fixed audio gains.

Figure 12 shows a block diagram of the instrumentation at the "Cliff Camp". The VHF telemetered signals from the four Remote Hydrophone Stations were received on military sonobuoy receivers type AN52 and were then amplified, filtered and recorded on either FM magnetic tape or oscilloscope photographs. Timing signals from the "Ice Camp" controlled a preset counter which was used to trigger the oscilloscope a precise time interval after the generation of each underwater tone-burst. These timing signals were also recorded on magnetic tape. The telemetry links did not appear to increase the signal-to-noise ratio of the signals from the hydrophones. This conclusion was reached as a result of checks made while the audio gains at the remote hydrophone stations were still under HF radio control.

APPENDIX B

TIDE CURRENT MEASUREMENTS

Tidal current velocities were obtained by measuring the fluid drag of a free flooding ping-pong ball and its four pound nylon monofilament line suspension. The angle of the line relative to the vertical was used to calculate the current velocity. The cost of the apparatus totalled 38 cents. In addition to our satisfied feelings of getting something for next to nothing it was apparent that this apparatus was reasonably efficient. The currents velocities were low, less than a tenth of a knot, and the current direction was also required so that the component of tide along the direction of sound path could be calculated. A magnetic compass was not usable and the current direction had to be referenced either to the surface or to a gyro-stabilized azimuth.

Figure 13 shows calibration curves for this simple current meter. The calibration was made at the laboratory by dragging the apparatus through a water tank at a constant rate. Most of the fluid drag was on the nylon line rather than on the ping pong ball, so that the calibration was dependent on the length of line used. In the field, a twenty-foot line was used; however, the uppermost seven feet were masked by the ice sheet. The plots of Figures 6 and 7 were derived from the calibration curve for a thirteen-foot suspension line.

Since the current velocity in the thirteen foot water layer immediately beneath the ice sheet was probably not uniform with depth, the field readings would have produced a weighted average value for the current in this layer. It seems to be a reasonable assumption that the water was not moving immediately beneath the ice sheet, and measurements by Sverdrup*** indicate that the boundary layer may be over ten feet thick. Thus, measurements of tidal current velocities could be expected to be low compared to those derived acoustically. It would obviously be desirable to make current measurements well free of the boundary layer but this procedure would involve far more complex equipment, such as the use of a Savonius Rotor for the speed of the current and a vane for direction of the current referenced to a gyro.

*** Reference 2, page 579.

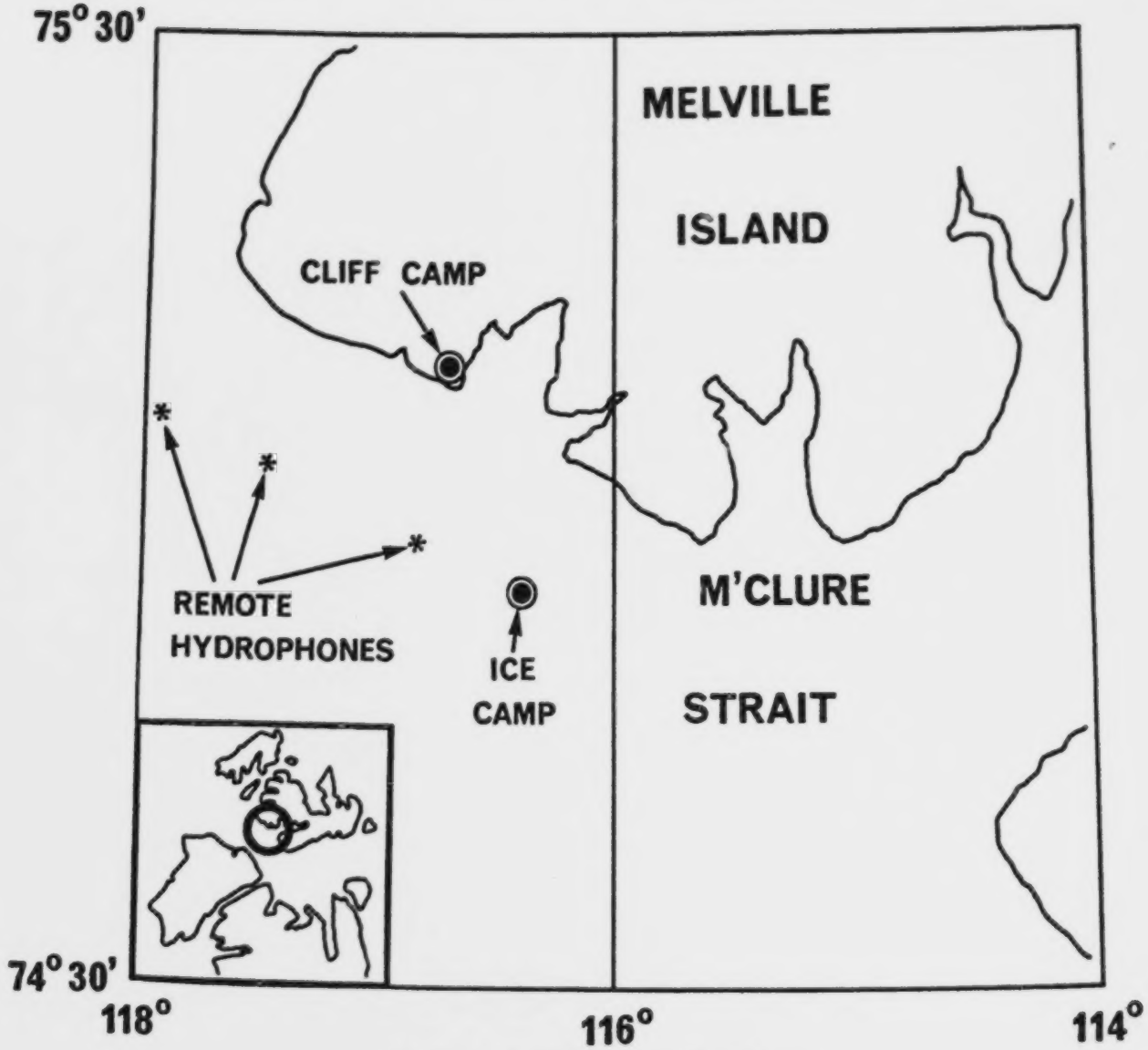

Figure 1: Location of the Experiment

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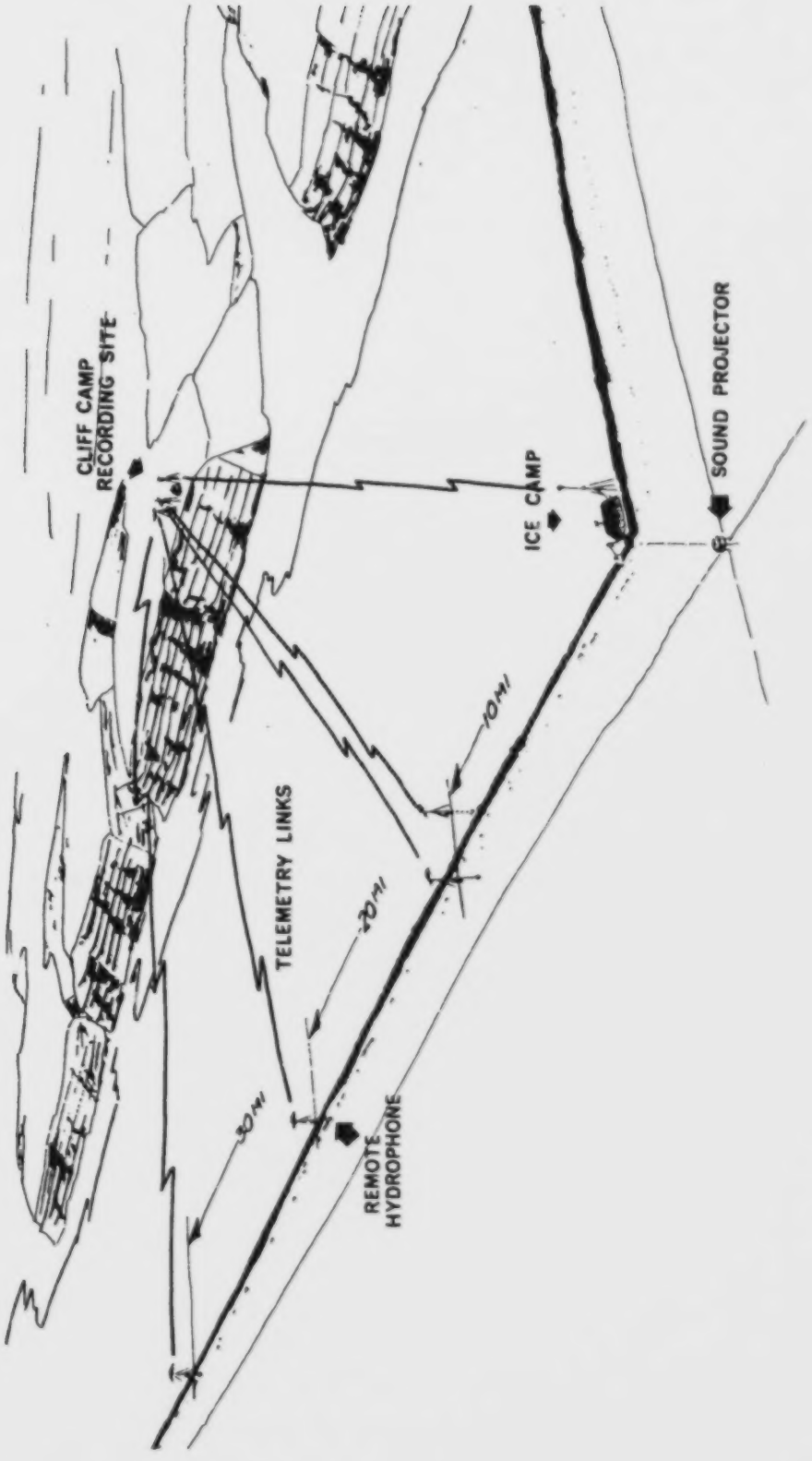

Figure 2: Geometry of the Experiment

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Figure 3: The transducer mounted on its stand ready for lowering.

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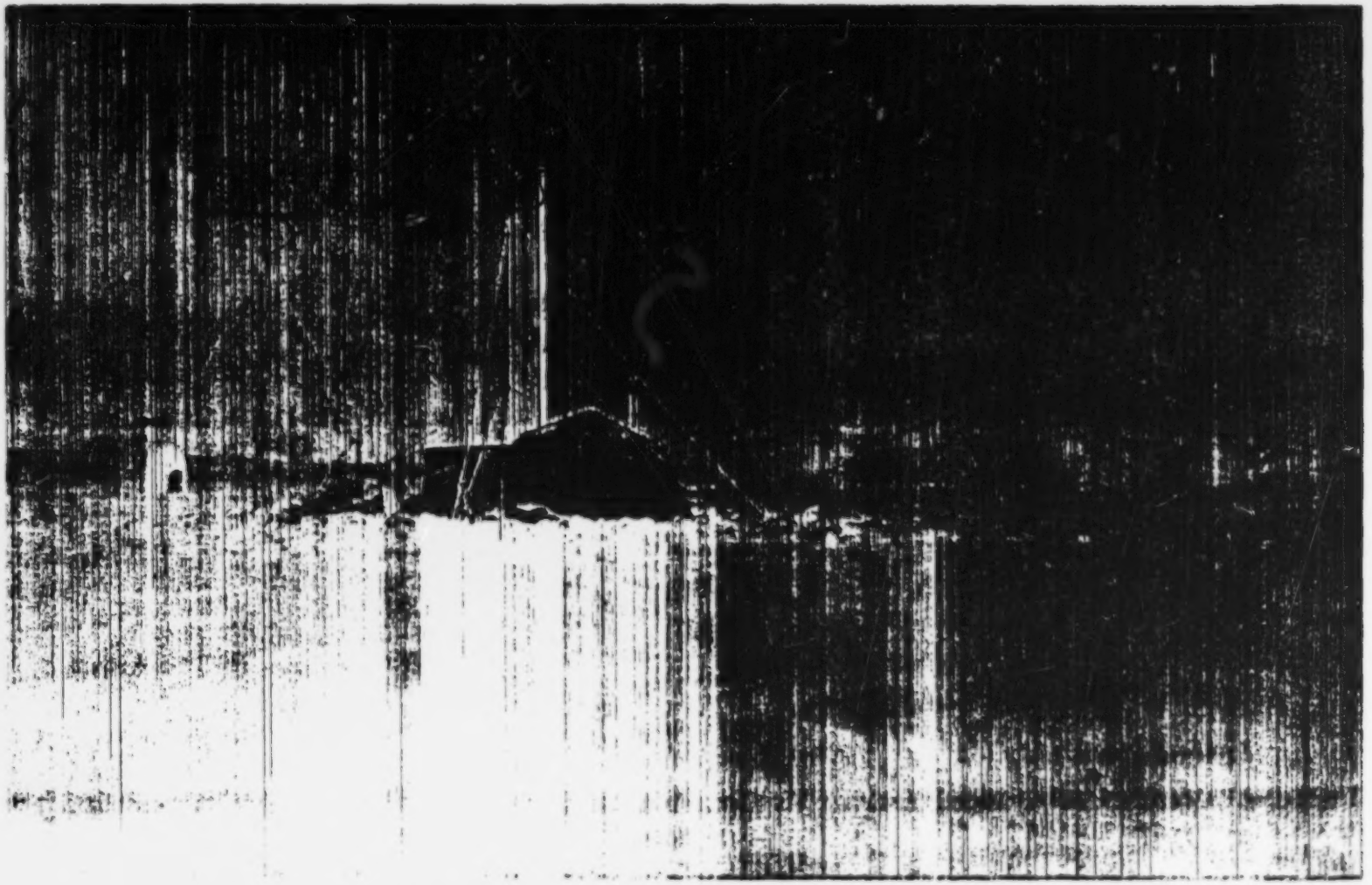

Figure 4: The "Cliff Camp" looking inland.

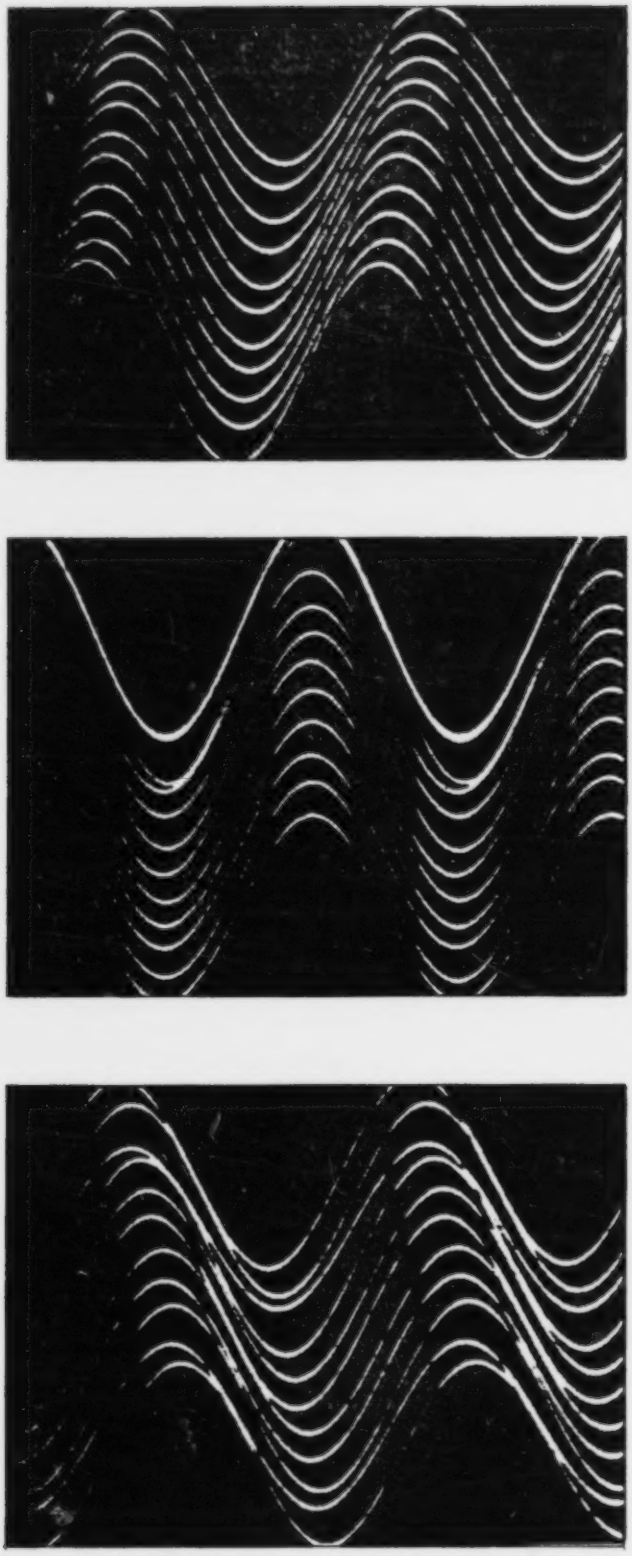

Figure 5: Portions of the sound signals received at thirty miles from the sound source. The frequency was 2150 Hz and the pulse repetition rate 45 secs. Each photograph shows the phase shift over eleven successive received pulses. Vertical displacement is used to separate the pulses. The three photographs were taken several hours apart.

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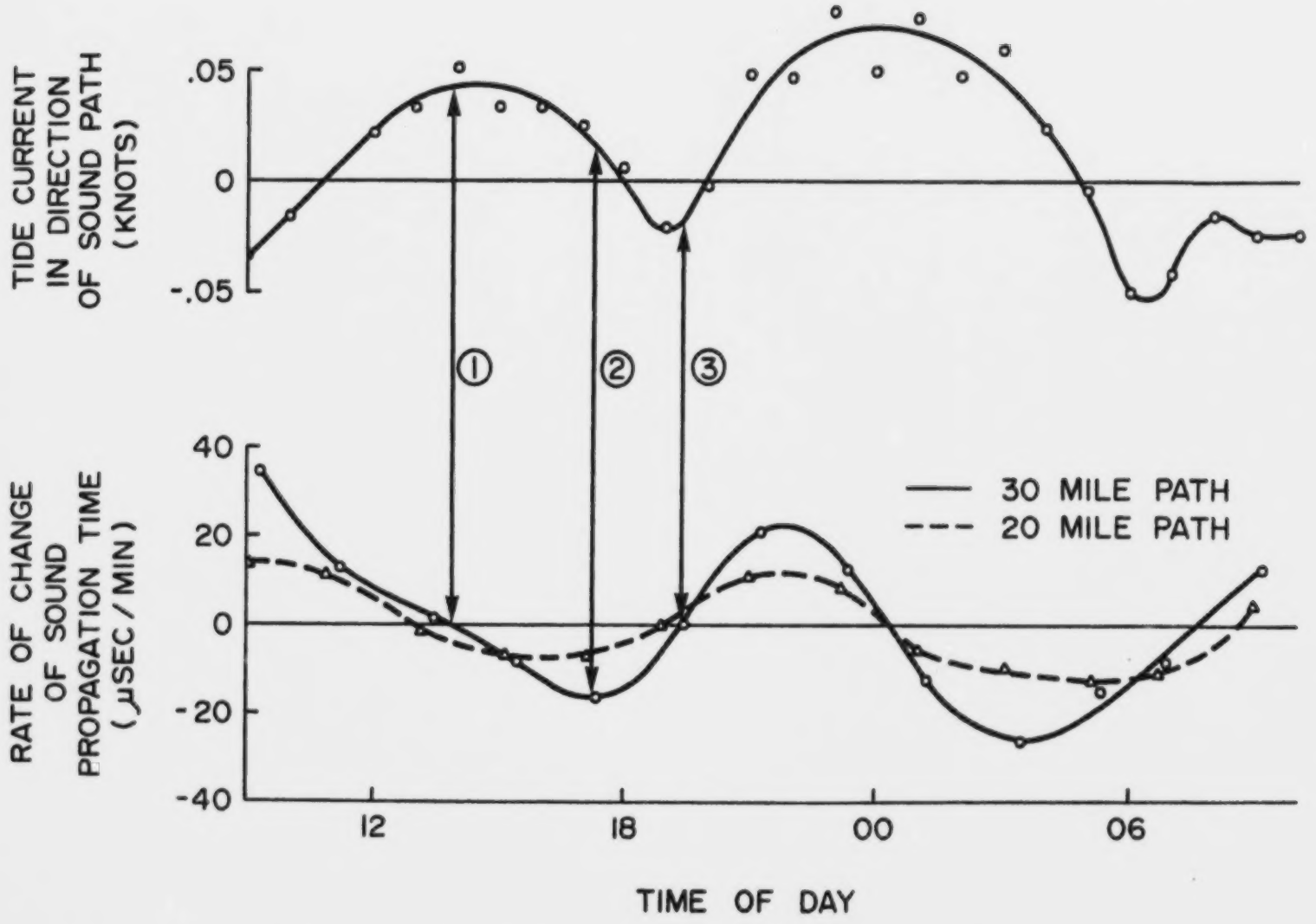

Figure 6: Graph showing the relation between tidal current and changes in the sound propagation time.

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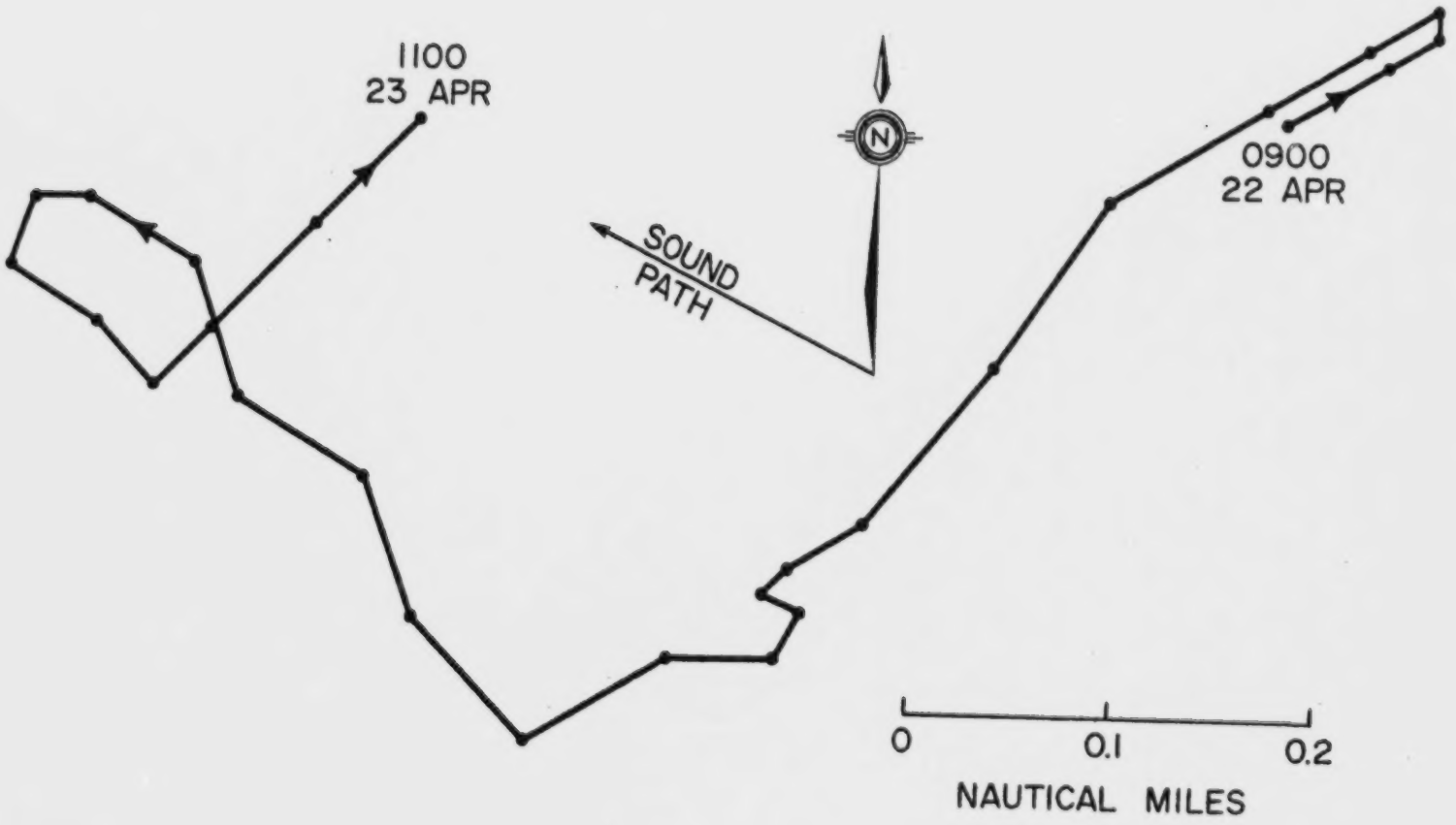

Figure 7: This progressive vector diagram shows the path a water particle would follow if the current were spatially uniform and had the value measured at the ice camp. It covers the period shown in Figure 6.

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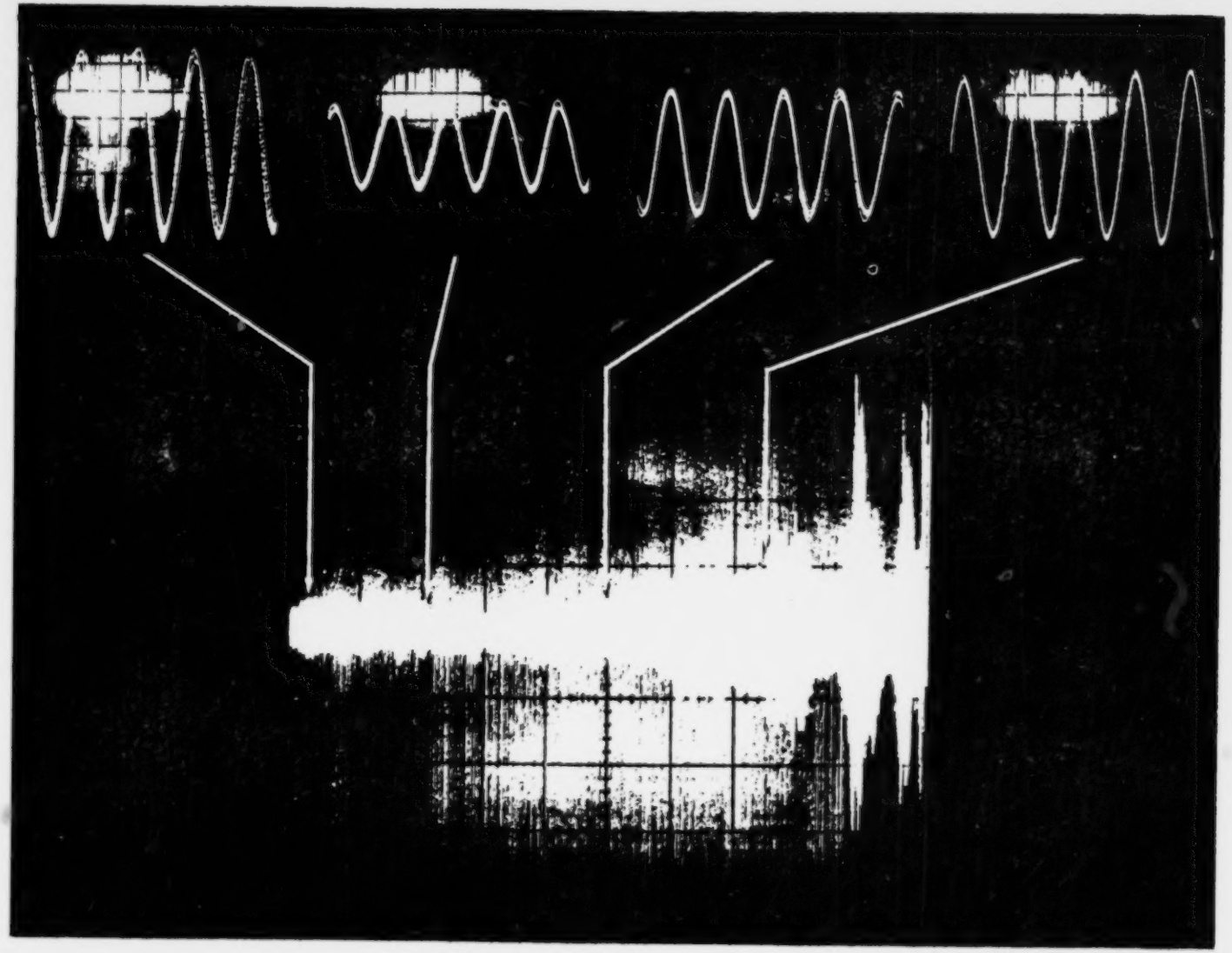

Figure 8: The first 10 seconds of reverberation received by a bottom mounted transducer. The expanded portions show a superposition of 5 separate reverberation returns, and this illustrates the amplitude and phase stability of the reverberation.

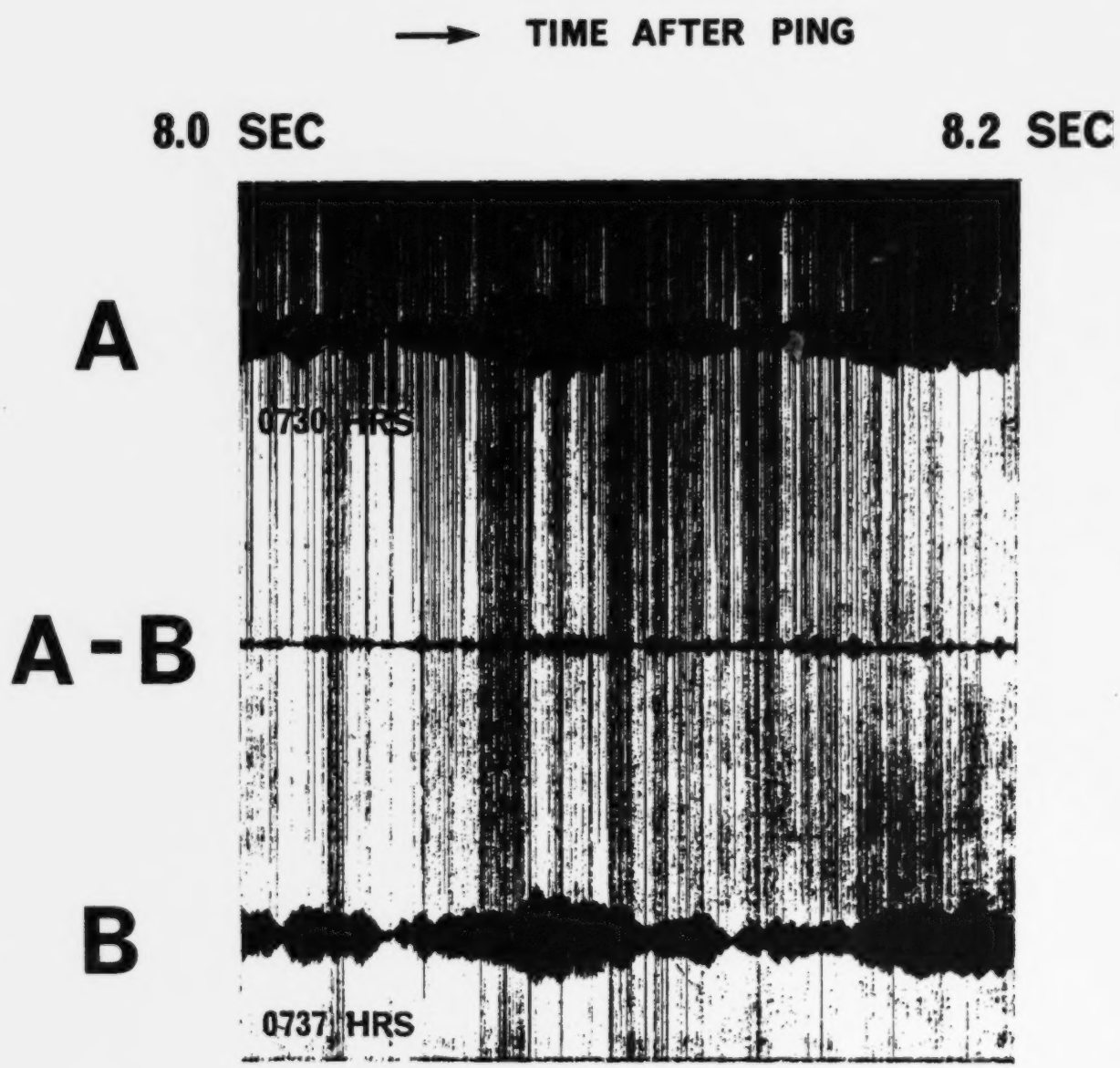

Figure 9: Computer plot of portions of two reverberation returns A and B and the difference between them A -B.

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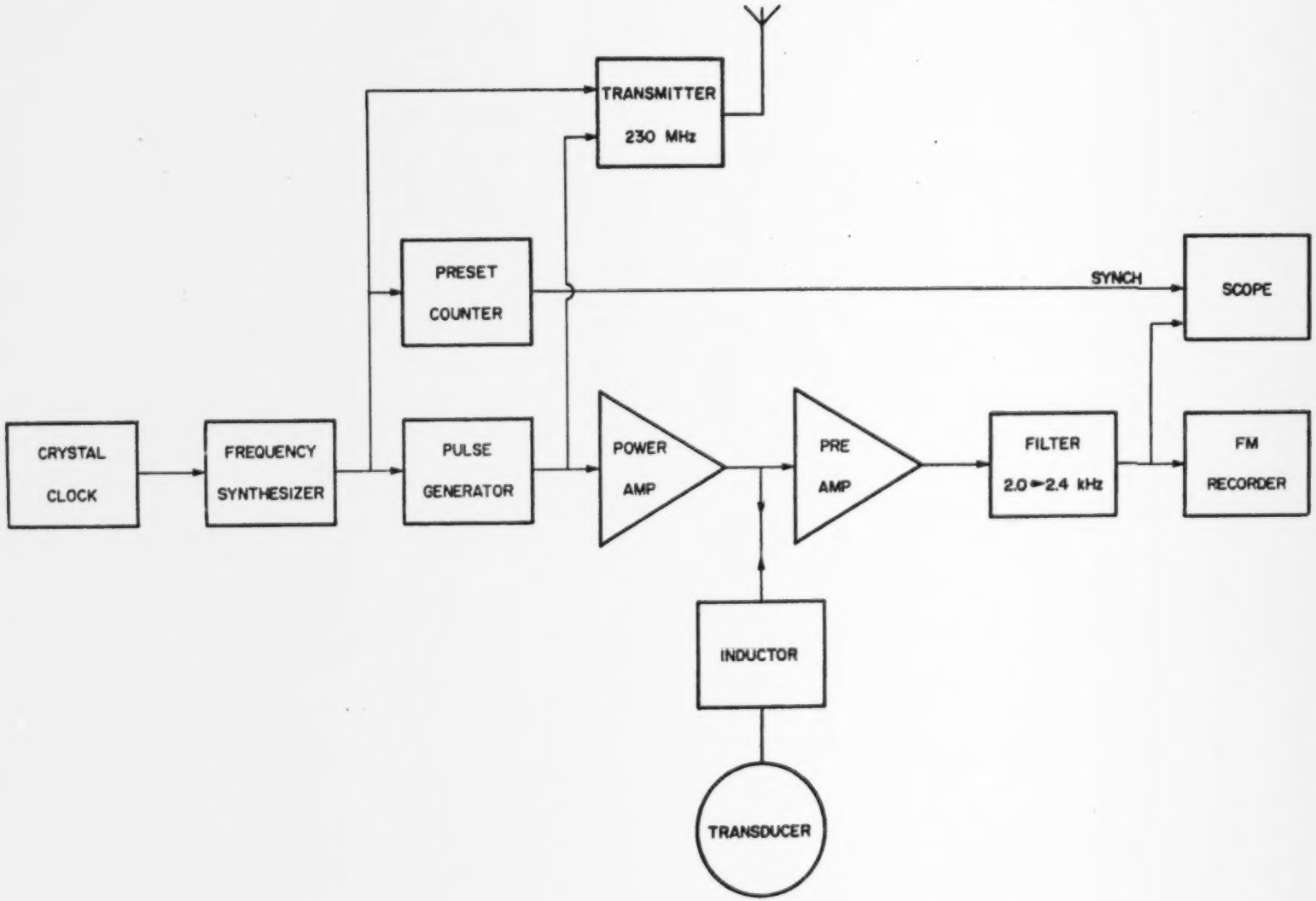

Figure 10: "Ice Camp" instrumentation.

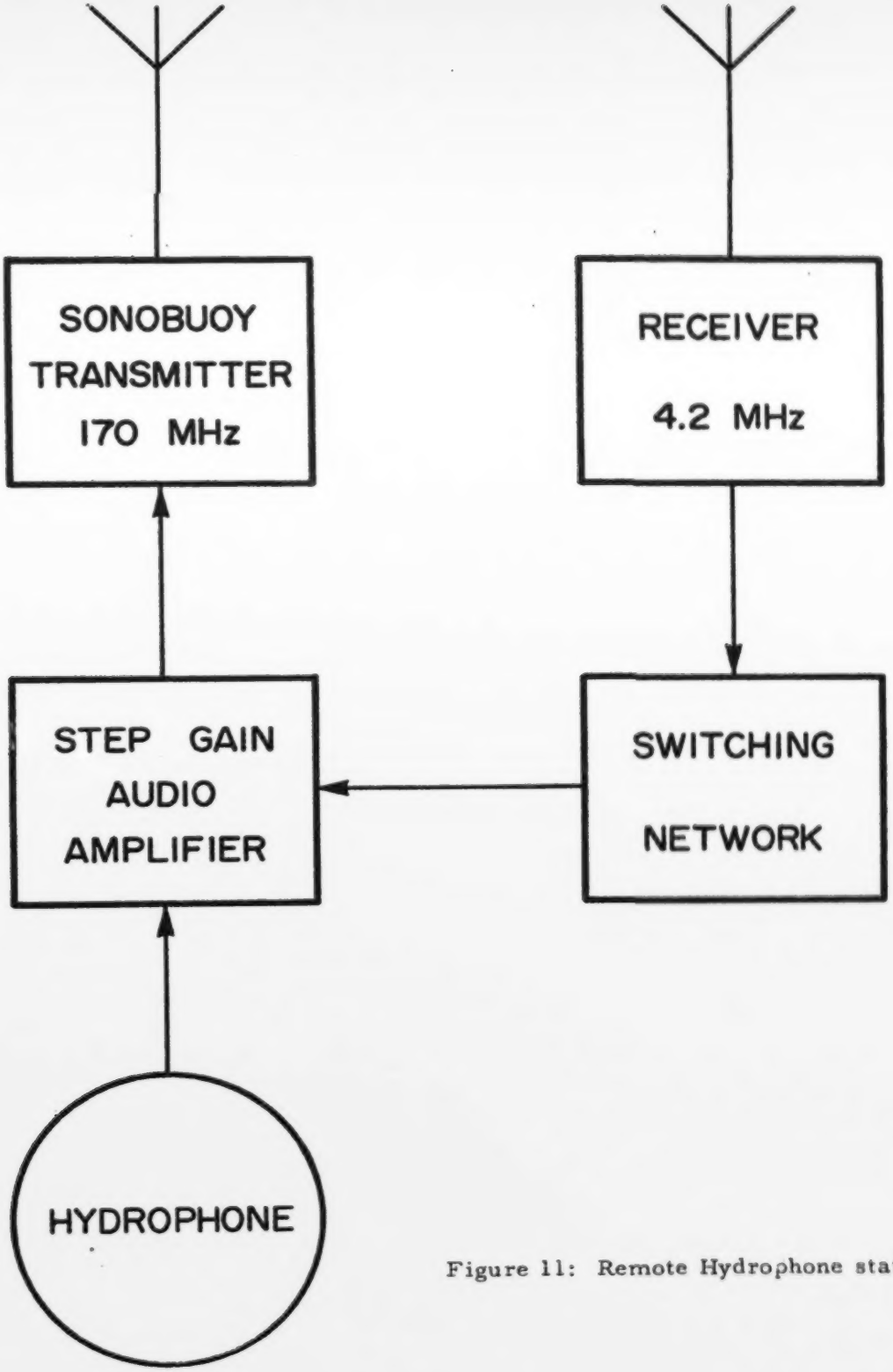

Figure 11: Remote Hydrophone station.

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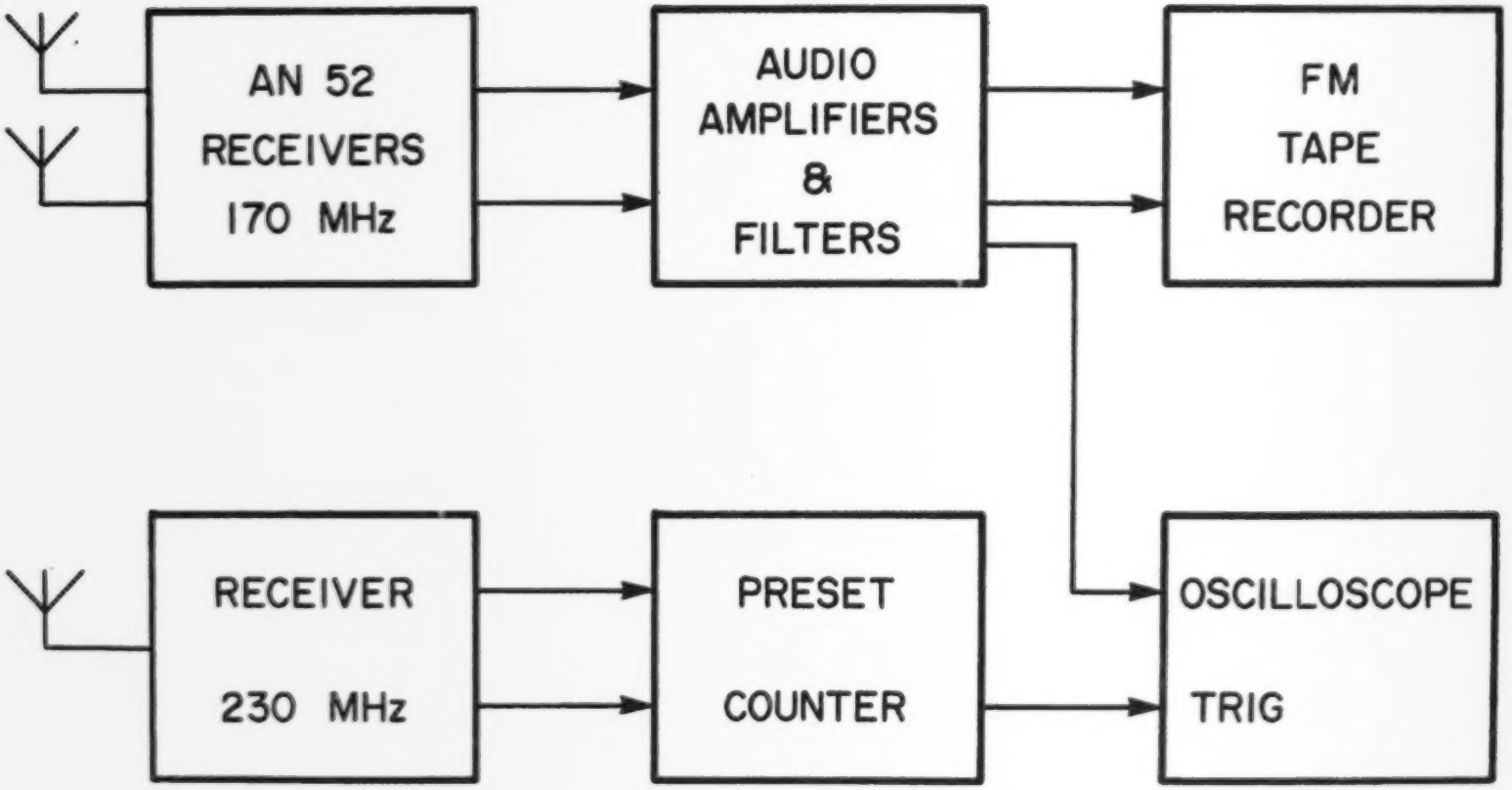

Figure 12: "Cliff Camp" instrumentation.

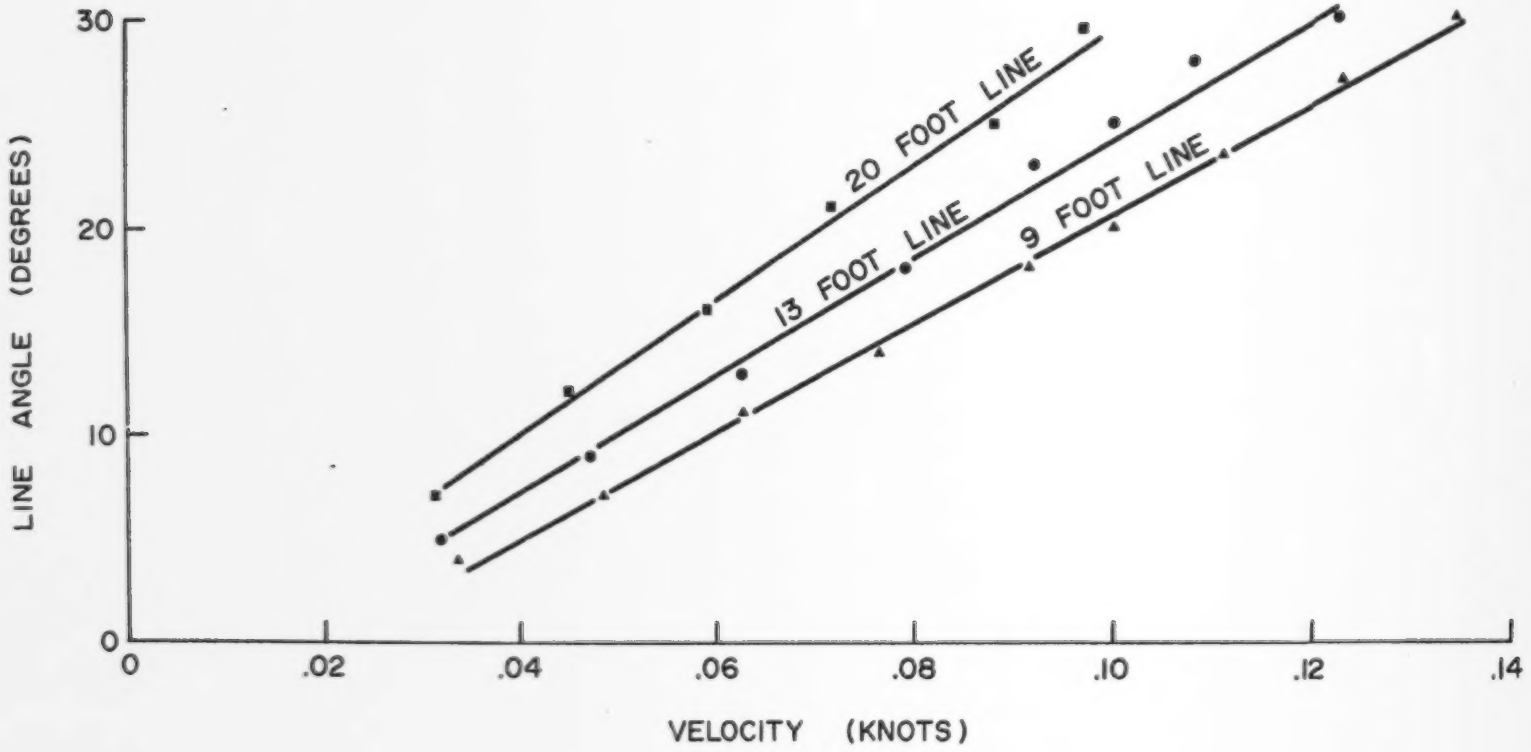

Figure 13: "Ping Pong" current meter calibration.

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